

3D Dynamical Modeling of Wind Accretion in Cyg X-3

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ABSTRACT

Cyg X-3 is a high mass X-ray binary consisting of a Wolf-Rayet star and a compact object in a very short orbital period of 4.8 h. The only confirmed microquasar with high energy gamma-ray emission, Cyg X-3 provides a unique opportunity to study the relationship between the accretion power and the power in high energy emission. Because of a compact orbit and a slow Wolf-Rayet wind, the flow structure around the compact object is thought to be strongly affected by the orbital motion, details of which can be obtained only by numerical simulations. In this paper, we report on the results from 3D hydrodynamic simulations of the wind accretion in Cyg X-3. For simplicity we adopt an anti-gravity-like force that emulates the radiative acceleration consistent with the beta-velocity wind. Due to the rapid orbital motion, the flow around the compact object has large density gradients. As a result, the accretion rate onto the compact object is significantly lower than that of the Bondi-Hoyle-Lyttleton rate. We also calculate the model X-ray light curve. Although it roughly agrees with the observed light curve, more detailed modeling is needed for detailed comparison.

KEY WORDS: accretion — stars: binaries — stars: individual (Cyg X-3) — X-rays: binaries

1. Introduction

Cyg X-3 is a unique laboratory for high energy astrophysics. It is a very bright, high mass X-ray binary consisting of a Wolf-Rayet star and a compact object, which is most likely a black hole, in a circular 4.8 h orbit. At present, it is the only microquasar from which variable GeV gamma-ray emission has been detected.

Cyg X-3 exhibits a 4.8 h modulation in multi-wavebands, which should provide important clues for the accretion/ejection mechanism. The X-ray modulation is basically explained by the absorption/scattering in the dense Wolf-Rayet wind, but the origin of the asymmetry (“slow rise, fast decay”) remains an open question (Zdziarski et al. 2012; Vilhu & Hannikainen 2013).

Fast orbital motion and slow acceleration of the wind (due to a lack of hydrogen) means that the Coriolis force could play an important role to shape the accretion pattern. Therefore, constructing a 3D dynamic model of wind accretion, taking account of the orbital motion, is important to understand the high energy activity of Cyg X-3.

2. Numerical Setup

We use a 3D SPH code to simulate the Wolf-Rayet wind around the compact object of Cyg X-3. The code uses the variable smoothing length and individual time-steps. The standard values of artificial viscosity parameters are adopted, i.e., $\alpha = 1$ and $\beta = 2$. In one simulation shown

below, the wind is launched spherically symmetrically and the optically-thin radiative cooling is taken into account, while in the other simulations, isothermal wind particles are ejected only in a narrow range of azimuthal and vertical angles toward the compact object, in order to optimize the resolution and computational efficiency. In these simulations, the Wolf-Rayet wind is assumed to have a velocity distribution of the form

$$v = v_{\infty}(1 - r/R_{\text{WR}})^{\beta}, \quad (1)$$

where v_{∞} is the terminal speed of the wind and R_{WR} is the radius of the Wolf-Rayet star. The stellar and wind parameters adopted are as follows: $M_{\text{WR}} = 10.3 M_{\odot}$, $R_{\text{WR}} = 6.1 R_{\odot}$, $M_{\text{X}} = 2.4 M_{\odot}$, $\dot{M}_{\text{WR}} = 6.5 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$, and $v_{\infty} = 1,700 \text{ km s}^{-1}$ (Zdziarski et al. 2013). The binary orbit is set in the x - y plane. In what follows, Phase 0 corresponds to the superior conjunction.

3. Numerical Results

Figure 1 shows the global structure of the $\beta = 2$ wind in the orbital plane. We notice that the Wolf-Rayet wind, which is launched spherically symmetrically, has a large-scale asymmetry around the compact object: significantly denser gas flow is seen on the rear side of the compact object than on the front side. This is because for $\beta = 2$ the wind speed near the compact object is comparable to the orbital speed of the compact object.

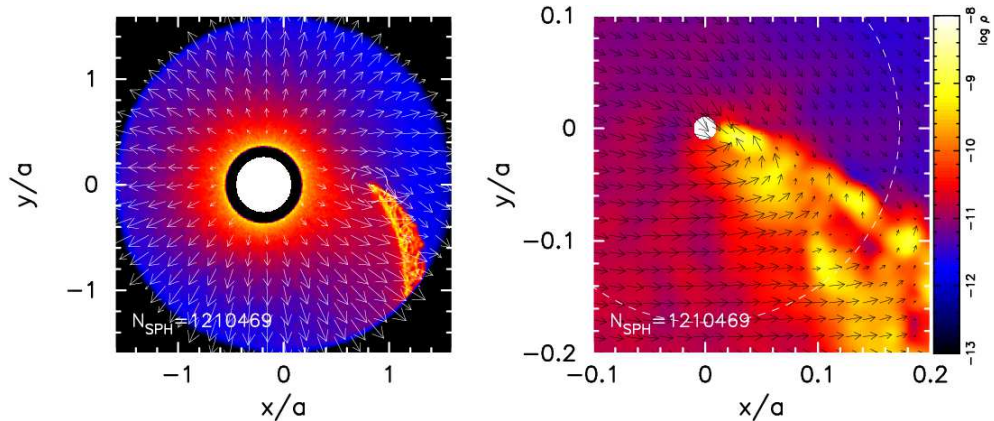


Fig. 1. Structure of a $\beta = 2$ Wolf-Rayet wind in the orbital plane. For numerical reasons, the wind particles are launched at the radius where the wind speed becomes twice the sound speed. In each plot, the color-scale plot shows the density distribution, while arrows denote the velocity vectors. The dashed circle shows the Bondi-Hoyle-Lyttleton accretion radius.

Table 1 compares the accretion rates in isothermal simulations for $\beta = 1, 2$, and 3 with the corresponding Bondi-Hoyle-Lyttleton (BHL) accretion rate. The simulated accretion rate is comparable with the BHL accretion rate for $\beta = 1$, but is significantly lower for $\beta \geq 2$. As a result, the increase in the simulated accretion rate with increasing β is weaker than in the BHL rate. This is because the flow around the compact object has a larger density gradient for larger β , while the BHL accretion rate is for a flow with uniform density distribution.

Table 1. Comparison between the simulated and BHL accretion rates.

β	simulation	simulated \dot{M} (10^{18} g s^{-1})	BHL \dot{M} (10^{18} g s^{-1})
1	isothermal	1.6	1.7
2	isothermal	2.8	4.1
2	radiative cooling	2.5	4.1
3	isothermal	4.0	8.6

Finally, Figure 2 shows simulated modulation in mass column and resulting X-ray light curves for a $\beta = 2$ wind with optically thin, radiative cooling. Moderate modulation is seen for small to intermediate inclination angles, while for high inclination angles, absorption/scattering by the accretion wake (phase 0.75) becomes remarkable. Unfortunately, the current model light curves do not reproduce the observed light-curve asymmetry. They are, however, computed for the first time based on the 3D dynamical simulation, where the effect of the orbital motion is also taken into account. We will continue our effort to better model the wind structure and absorption/scattering by the wind.

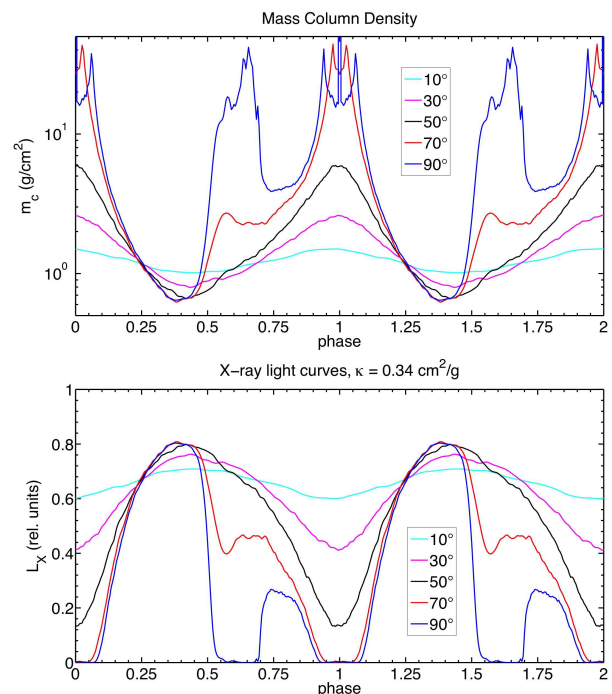


Fig. 2. Simulated modulation in mass column and resulting X-ray light curves for a $\beta = 2$ Wolf-Rayet wind with radiative cooling. The degrees in the legends are inclination angles.

We thank Shunji Kitamoto for helpful comments on the X-ray behavior of Cyg X-3. This work was partially supported by the JSPS Grants-in-Aid for Scientific Research (C) (24540235).

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